

The MAGIC view of PG 1553+113

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We present the results of five years (2005-2009) of MAGIC observations of the BL Lac object PG 1553+113 at very high energies (VHEs). Adding the new data set (2007-2009) to previous observations, this source becomes one of the best long-term followed sources at energies above 100 GeV. In the last three years of data, the flux level above 150 GeV shows a marginal variability. Simultaneous optical data also show only modest variability that seems to be correlated with VHE gamma-ray variability. We also performed a temporal analysis of all available *Fermi*/LAT data of PG 1553+113 above 1 GeV. Finally, we present a combination of the mean spectrum measured at VHE with archival data available for other wavelengths. The mean Spectral Energy Distribution (SED) can be modeled with a one-zone SSC model, which gives the main physical parameters governing the VHE emission in the blazar jet.

I. INTRODUCTION

PG 1553+113 is a BL Lac object located in the Northern hemisphere. It was discovered in 1986 by Green et al. [13]. As for many objects of this class, its redshift is uncertain. Several attempts to determine its distance were done in the past, e.g. [19]. Recent determinations suggest $z \sim 0.4$ [11, 15]. At VHE the blazar was detected in 2005 by the H.E.S.S. telescopes system [3] and soon after confirmed by MAGIC [6].

II. MAGIC OBSERVATIONS

MAGIC is a stereo system composed of two new generation Imaging Atmospheric Cherenkov Telescopes located on La Palma, Canary Islands, Spain at ~ 2200 m asl. It observes the VHE γ -ray sky at energies above 60 GeV. Data presented here were collected before Autumn 2009, when MAGIC was operating with a single telescope. For a detailed description of the performances, see [5].

Since 2005, PG 1553+113 was monitored by MAGIC [4, 7, 8]. Here we present the results of the analysis of 2007/08/09 data. The data (partly taken in moderate light conditions, i.e. moon light) were analyzed using the standard MAGIC analysis chain [5, 9]. Severe quality cuts based on event rate after night sky background suppression were applied to the sample; 28.7 hours of good quality data remained after these cuts, out of which 25.3 can be used for the spectral analysis (Table I). The energy threshold is ~ 90 and ~ 80 GeV for 2006 and 2007 observations respectively, ~ 150 for 2008, due to poor observing conditions, and 160 GeV for 2009 data, due to moderate moon light observation. Further details of the data analysis and signal detection of the sample are

discussed in [7].

III. RESULTS

A. Integral Flux

The lower panel of Figure 1 displays the VHE integral flux above 150 GeV of PG 1553+113 measured from 2007 to 2009 by MAGIC with a variable binning. For comparison, the daily flux levels measured in 2005 and 2006 are shown, as extrapolated from the published data [4, 6]. The measured flux shows modest variations (4% to 11% of the Crab Nebula flux above 150 GeV, Table I).

The simultaneous optical R-band data are outlined in the first panel. These data are collected on a nightly basis by the Tuorla Observatory Blazar Monitoring Program [20] [18] using the KVA 35 cm telescope at La Palma and the Tuorla 1 meter telescope in Finland. A marginal activity is followed by the optical flux, whose variations are limited within a factor of four. Figure 2 shows the result of a correlation study between optical and TeV simultaneous observations. A linear relation among the two components has a 74% probability (χ^2 test), which suggests a correlation between these two extreme energy bands.

The public X-ray data, results of an automatic analysis performed by the *Swift*/XRT Monitoring Program [21], are shown in the second panel of Fig 1. In contrast to optical and VHE bands, the X-ray light curve shows a pronounced variability.

In the third panel, the *Fermi*/LAT light curve of PG 1553+113, computed in 10-day bins, is displayed. *Fermi* data presented are restricted to the 1 GeV-100 GeV energy range and were collected from MJD 54682 (2008 August 4) to MJD 55200 (2010 January

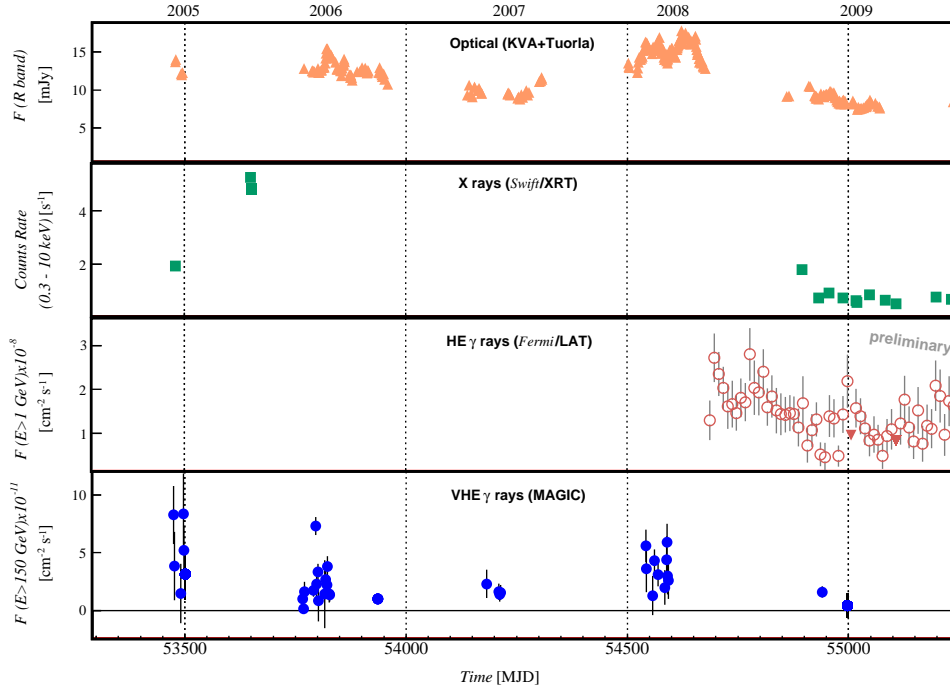


FIG. 1: – Multiwavelength light curve of PG 1553+113 from 2005 to late 2009. From upper to lower panel: optical flux in the R-band (triangles), X rays counts rate (squares), γ rays above 1 GeV (open circles), and VHE γ rays above 150 GeV measured by MAGIC (filled circles). The error bars reported have 1σ significance. Downward triangles, in the third panel, refer to 2σ upper limits on the source flux above 1 GeV.

| Year | Good quality data [h] | Energy Threshold [GeV] | $F(> 150 \text{ GeV}) / 10^{-11}$ [$\text{cm}^{-2} \text{s}^{-1}$] | $F(> 150 \text{ GeV})$ [Crab %] | Γ |
|---------|--------------------------|---------------------------|---|------------------------------------|---------------|
| 2005+06 | 19 | 90 | 2.8 ± 0.5 | 9% | 4.2 ± 0.2 |
| 2007 | 11.5 | 80 | 1.40 ± 0.38 | 4% | 4.1 ± 0.3 |
| 2008 | 8.7 (6.9 for spectrum) | 150 | 3.70 ± 0.47 | 11% | 4.3 ± 0.4 |
| 2009 | 8.5 (6.9 for spectrum) | 160 | 1.63 ± 0.45 | 5% | 3.6 ± 0.5 |

TABLE I: – Observation details and spectra of the individual years of observations of PG 1553+113.

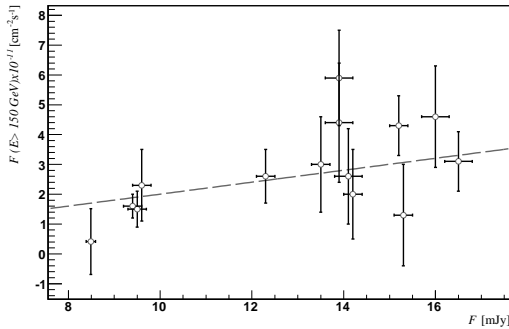


FIG. 2: – Correlation study between PG 1553+113 optical R-band flux and VHE γ ray integral flux above 150 GeV observed from 2006 to 2009.

4) in survey mode. The details on the analysis performed can be found in [7]. A steady emission above

1 GeV has a probability smaller than 0.1% and is ruled out.

B. Differential Flux

The differential energy spectra observed from PG 1553+113 by MAGIC each year from 2007 to 2009 are shown in the left plot of Figure 3. As for other blazars, each spectrum can be well fitted with a power law function. The resulting indices are listed in the last column of Table I. The systematic uncertainty is estimated to be 35% in the flux level and 0.2 in the power index [5]. Except for 2009 sample, whose significance is rather low and corresponding errors noticeably large, the indices describing the spectra are compatible. This indicates that the shape of the emitted spectrum does not change, even if the total flux

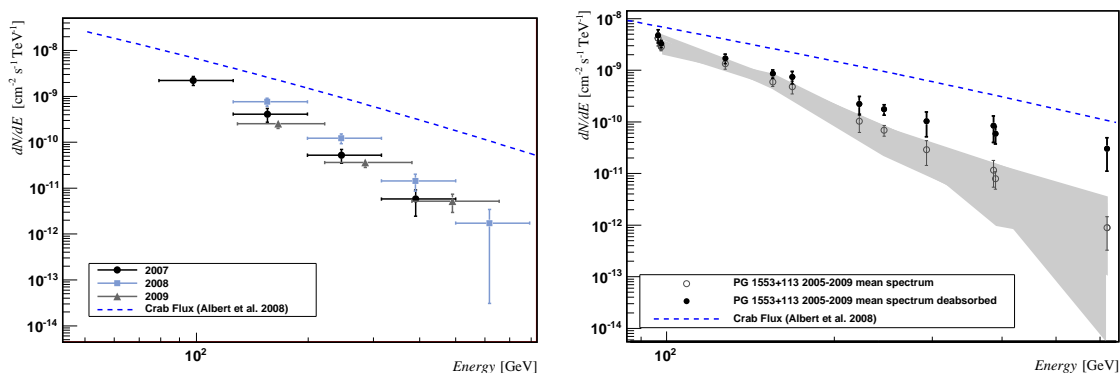


FIG. 3: – Differential energy spectra from PG 1553+113. Left Figure: comparison between 2007, 2008 and 2009 spectra. Right Figure: superimposition of 2005-2006 spectrum, from [6], to 2007-2009 mean spectrum and corresponding deabsorption for $z = 0.4$ using the EBL model of [12]. In both figures, the fit of the Crab Nebula spectrum measured by MAGIC [5] is superimposed for comparison.

shows hints of (small amplitude) variability.

The right plot of Figure 3 shows the combined differential spectrum of PG 1553+113 from 2007 to 2009, superimposed to the 2005-2006 spectrum measured by MAGIC ($\Gamma = 4.21 \pm 0.25$, [6]). The gray band represents the systematic effect on the combined spectrum result of different unfolding methods. In order to estimate the intrinsic spectrum emitted by the source, the effect of absorption of VHE photons in the interaction with the extragalactic background light (EBL) should be considered. Assuming the background model proposed in [12] and a redshift $z = 0.40$, we obtain an intrinsic spectrum compatible with a power law of index 3.09 ± 0.20 , as drawn in the right plot of Figure 3.

C. Modeling the SED

Figure 4 shows the SED of PG 1553+113 obtained using historical data and the MAGIC spectra described above.

The mean overall SED can be fitted with a simple one-zone SSC model [14]. The corresponding model parameters are the minimum, break and maximum electron Lorentz factors and the low and high energy slope of the electron energy distribution, the magnetic field intensity, the electron density, the radius of the emitting region and its Doppler factor, listed in Tab II. We also give the derived power carried by electrons, magnetic field, protons (assuming one cold proton per emitting relativistic electron) and the total radiative luminosity.

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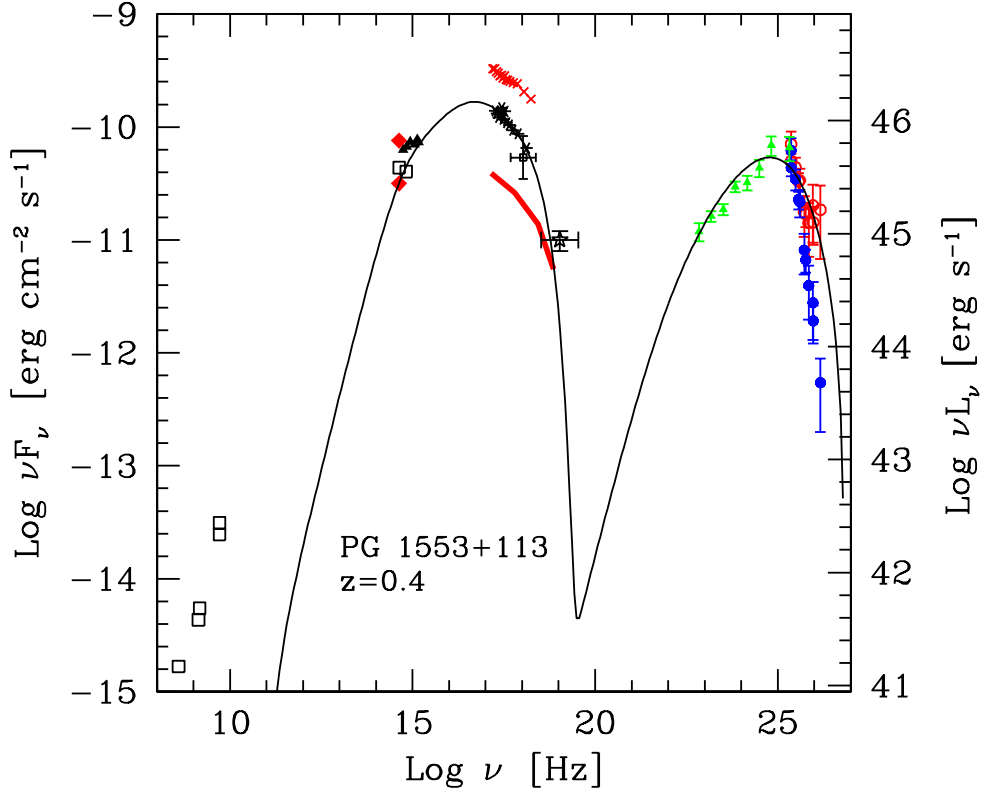


FIG. 4: – SED of PG 1553+113. Open black squares displaying radio-optical data are from NED. In the optical band, we also show (red diamonds) the KVA minimum and maximum flux measured in the period covered by MAGIC 2005-2009 observations together with optical-UV fluxes from *Swift*/UVOT (filled black triangles, from [17]). For the X-ray data, two *Swift*/XRT spectra taken in 2005 (high flux state, red crosses, and intermediate state, black asterisks, from [17]) are given, and a *Suzaku* spectrum taken in 2006 (continuous red line, from [16]). In addition, the average 14-150 keV flux measured by *Swift*/BAT during the first 39 months of survey [10] is shown (black star), and the average *RXTE*/ASM flux between March 1 and May 31, 2008 (small black square), from quick-look results provided by the *RXTE*/ASM team. The green triangles correspond to the LAT spectrum averaged over ~ 200 days (2008 August-2009 February) from [2]. For MAGIC, we report the 2005-2006 and 2007-2009 observed spectra (filled circles) and the same spectra corrected for the absorption by the EBL (red open circles).

| γ_{\min} | γ_b | γ_{\max} | n_1 | n_2 | B | K | R | δ | P_e | P_B | P_p | L_r |
|--------------------|--------------------|--------------------|-------|-------|-----|-------------------------------------|-----------------------|----------|--------------------------|--------------------------|--------------------------|--------------------------|
| [10 ³] | [10 ⁴] | [10 ⁵] | | | [G] | [10 ³ cm ⁻³] | [10 ¹⁶ cm] | | [10 ⁴⁴ erg/s] | [10 ⁴⁴ erg/s] | [10 ⁴⁴ erg/s] | [10 ⁴⁴ erg/s] |
| 2.5 | 3.2 | 2.2 | 2.0 | 4.0 | 0.5 | 5.35 | 1 | 35 | 2.2 | 1.5 | 0.34 | 6.3 |

TABLE II: – Input model parameters for the model shown in Fig 4. See text for details.

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